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THESIS

DESIGN OF A DATA ACQUISITION
AND REDUCTION SYSTEM FOR FATIGUE TESTING

by

Jerry Wayne Dalton

September 1981

Thesis Advisor:

Gerald H. Lindsey

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damage at a stress concentration is calculated from the applied local stresses using Miner's Law.

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Design of a Data Acquisition
and Reduction System for Fatigue Testing

by

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Lieutenant, United States Navy
B.S., University of Texas at Austin, 1975

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

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September 1981

ABSTRACT

A data acquisition and reduction system has been created for aircraft materials fatigue testing. The system uses an HP-9835 Desktop Calculator, an HP-2240A Measurement and Control Processor and a Materials Testing System loading machine. Three different computer programs on the HP-9835 are used to analyze material properties, simulate inflight fatigue loading and compute fatigue damage at a stress concentration. The flight loads are selected from Mil Spec 8866 and applied in a random order. The fatigue damage at a stress concentration is calculated from the applied local stresses using Miner's Law.

TABLE OF CONTENTS

I.	INTRODUCTION-----	9
II.	CONCEPTS-----	10
	A. STRESS AND STRAIN CALCULATIONS-----	10
	B. MILITARY SPECIFICATIONS FOR FATIGUE-----	12
	C. STANDARD USED FOR MATERIAL PROPERTIES-----	13
III.	DESCRIPTION OF ACQUISITION SYSTEM-----	19
IV.	DESCRIPTION OF PROGRAMS-----	24
	A. PROGRAM AXIAL-----	24
	B. PROGRAM FLTTST-----	27
	C. PROGRAM DAMAGE-----	29
V.	SAMPLE TEST-----	32
	A. PROGRAM AXIAL-----	32
	B. PROGRAM FLTTST-----	34
	C. PROGRAM DAMAGE-----	38
VI.	CONCLUSIONS-----	43
	APPENDIX A (Program Flow Charts)-----	44
	APPENDIX B (Program Listings)-----	47
	LIST OF REFERENCES-----	62
	INITIAL DISTRIBUTION LIST-----	63

LIST OF TABLES

I.	Flight Load Spectrum A-----	13
II.	Data Points Used for Regression Equations-----	15
III.	Regression Coefficients-----	16
IV.	Regression Equation Correlation-----	17
V.	Random Number for Selecting Maneuver Load-----	28
VI.	Sample Load Spectra-----	36
VII.	Step Size Comparisons-----	39
VIII.	Ten Cycle Load Spectrum-----	40
IX.	Three Hour Flight Simulation Test-----	41
X.	Two Hour Flight Simulation Test-----	42

LIST OF FIGURES

1.	Sample Test Specimen-----	11
2.	S-N Diagram for 7075-T6 Aluminum-----	14
3.	HP-9835 Desktop Computer-----	20
4.	HP-2240A Measurement and Control Processor-----	21
5.	Materials Testing System (MTS)-----	22
6.	AXIAL Tension Test-----	35
7.	Sample Random Loading-----	37

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I. INTRODUCTION

Today's high cost of aircraft dictates that the lifetimes of existing and new aircraft be extended as long as possible. The data acquisition system and computer programs described in this thesis will permit more realistic fatigue testing of aircraft materials; thereby enabling the engineer to predict and design more accurately for fatigue life.

The programs are set up to start with a standard tension test to determine the modulus of elasticity and the Ramberg-Osgood coefficients to model the plastic region. The second program is for flight load simulation of a specific number of flight hours to be applied to a specimen with a given stress concentration. This program was designed to apply loads that would be experienced by fighter aircraft, the loads being randomly ordered after being selected from the Military Specification 8866 1000 flight hour spectrum. The load data from this test is stored in sequence on magnetic tape, and local strain information is gathered at the point of stress concentration via pictures of photo-elastic patterns taken during the test. The last program assesses the damage incurred by the specimen during the flight simulation. This program is specialized to predict damage for specimens fabricated from 7075-T6 Aluminum.

II. CONCEPTS

A. STRESS AND STRAIN CALCULATIONS

Lindsey has developed [Ref. 1] a series of equations for calculating local stresses at stress concentration sites, which use a nonlinear stress-strain law and account for residual stresses and strains. The analysis assumes that the notch tip behaves in many respects like a uni-axial tension specimen with a Ramberg-Osgood description.

$$\epsilon = \frac{\sigma}{E} + \beta \left(\frac{\sigma}{E} \right)^n \quad (1)$$

Loading the specimen of Figure 1 to a nominal stress of S psi, the local stress can be found by solving

$$K_t S = \sigma [1 + \beta \left(\frac{\sigma}{E} \right)^{n-1}] \quad (2)$$

where

K_t = Elastic Stress Concentration Factor

During the unloading portion of the cycle, Lindsey showed, via energy considerations, that the residual stress was given by

$$\sigma_R = \sigma - \left[\sigma^2 + \frac{2n\beta E^2}{n+1} \left(\frac{\sigma}{E} \right)^{n+1} \right]^{\frac{1}{2}} \quad (3)$$

where σ is the local stress at the notch at the peak of the loading cycle as found from Equation (2) above. This stress will be compressive and will be non-zero only if σ exceeds

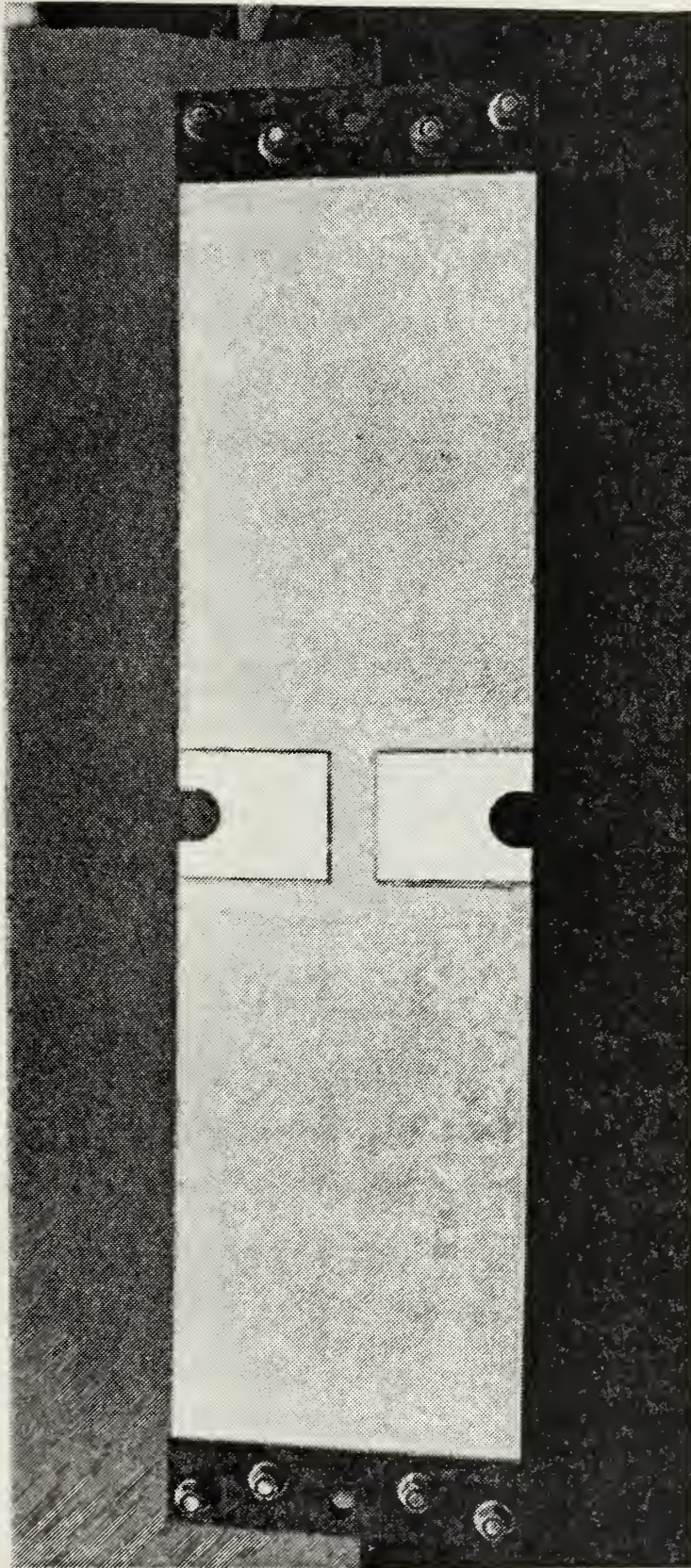


Figure 1. Sample Test Specimen

the proportional limit by a significant amount. The residual strain is positive and given by

$$\epsilon_R = \frac{\sigma_R}{E} + \beta \left(\frac{\sigma}{E} \right)^n \quad (4)$$

These values of stress and strain become the starting points for the next cycle, and the R fatigue parameter is calculated taking the residual stress into account. (The R value is the ratio of the minimum stress to the maximum stress.) The elastic stress in subsequent cycles is given by

$$\sigma = \sigma_R + K_r S - E \epsilon_R \left[1 + \frac{S}{S_{\text{Last Yield}}} \right] \quad (5)$$

At the next yield, a new residual stress and strain must be calculated from Equations (3) and (4).

B. MILITARY SPECIFICATIONS FOR FATIGUE

In order to analyze materials and structures for fatigue, it is necessary to have some knowledge of the types of loads and the number of loading cycles that the structure will be subjected to. For this purpose Military Specification 8866 Flight Loading Spectrum A has been chosen (Table I). This spectrum was chosen by the military for loadings that were expected on fighter-type aircraft for each 1000 hours of flight time. The military expects these aircraft to have a lifetime of 4000-6000 hours under this type of loading.

TABLE I
FLIGHT LOAD SPECTRUM A

<u>% Limit Load</u>	<u>Number of Cycles</u>
35	17,000
45	9,500
55	6,500
65	4,500
75	2,500
85	1,360
95	440
105	150
115	40
125	16

C. STANDARD USED FOR MATERIAL PROPERTIES

The reference material specifications for fatigue life were taken from NACA TN 2324 [Ref. 2]. Testing was done on sheet 75S-T6 Aluminum (Al 7075-T6) for various R values. The results of these tests were plotted in Figure 2. Regression equations were formulated using the BMDP Biomedical Computer Programs [Ref. 3] by inputting the data points in Table II that were selected off Figure 2.

The best regression formula (Table III) was found by using the actual R value and the stress divided by 10,000. The output value was the logarithm of the number of cycles

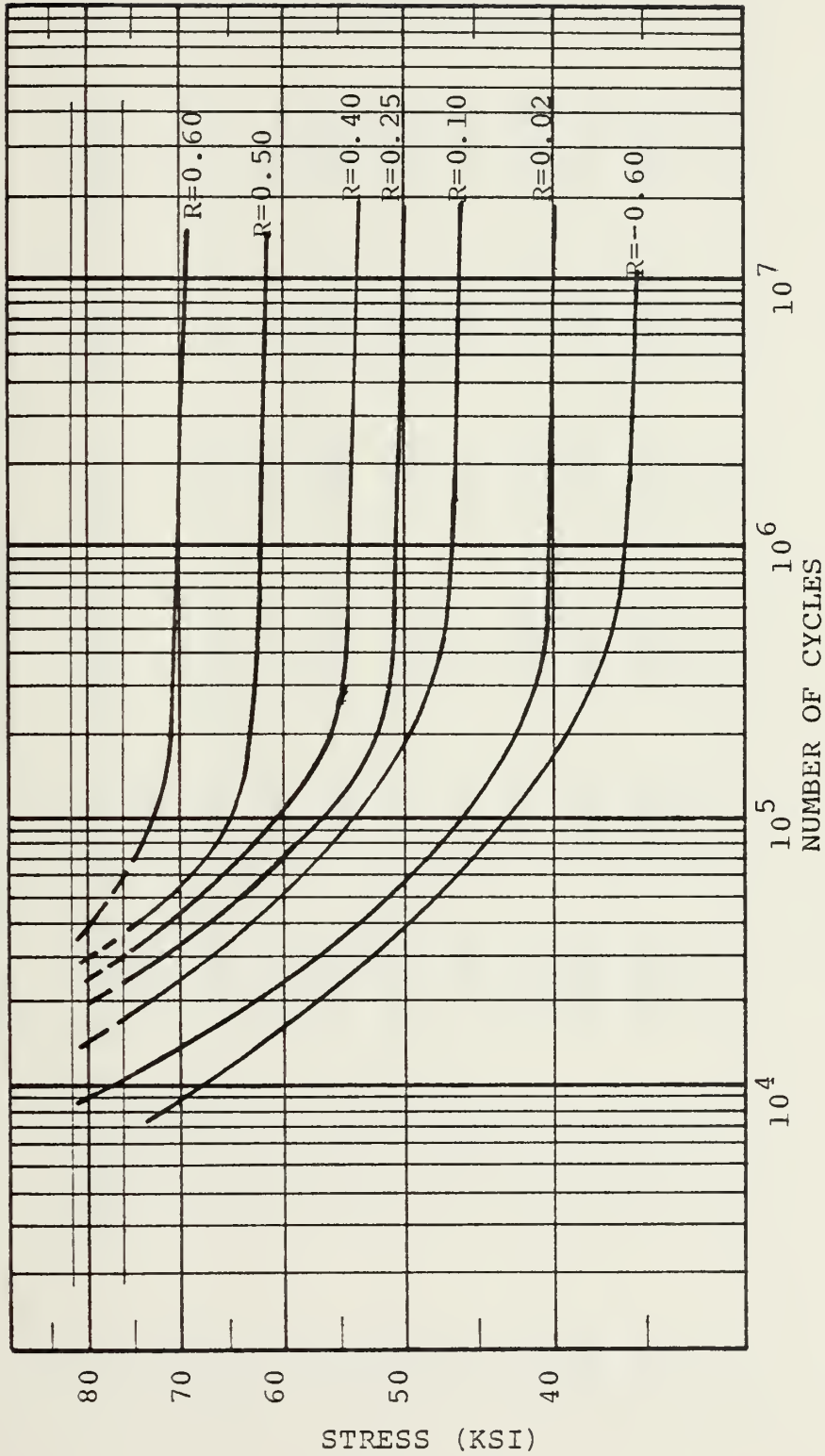


Figure 2. S-N Diagram for 7075-T6 Aluminum

TABLE II

DATA POINTS USED FOR REGRESSION EQUATIONS

<u>N</u>	<u>LOG N</u>	<u>R=-0.60</u>	<u>R=0.02</u>	<u>R=0.10</u>	<u>R=0.25</u>	<u>R=0.40</u>	<u>R=0.50</u>	<u>R=0.60</u>
1E4	4.0000	67500	77000	-	-	-	-	-
2E4	4.3010	57000	62000	73500	80000	-	-	-
3E4	4.4771	52800	57000	67000	72000	76100	81000	-
4E4	4.6021	49900	53500	63000	67200	71400	75000	79200
6E4	4.7782	46500	49500	58000	61500	65500	69000	75000
1E5	5.0000	43200	45500	54000	56500	60500	64800	72500
2E5	5.3010	39100	42200	49400	52000	55700	62500	70500
3E5	5.4771	37500	41000	48300	51000	54800	62300	70200
6E5	5.7782	35200	40500	47000	50500	54000	62000	70000
1E6	6.0000	34500	40100	46500	50300	53900	61900	69800

TABLE III
REGRESSION COEFFICIENTS

<u>Term</u>	<u>Coefficient</u>
INTERCEPT	12.6452
S	-1.92662
S ⁴	2.81098E-3
S ⁸	-3.10691E-7
R ²	-12.8099
R ⁶	212.476
R ⁸	-86.7650
SR	3.68800
S ³ R	-0.112720
S ⁵ R	1.04762E-3
S ⁷ R ³	3.39637E-6
S ³ R ⁴	-3.50885E-2
S ⁴ R ⁶	-1.61827E-2
SR ⁹	-34.4642

S = Stress/10000

R = Minimum Stress/Maximum Stress

to failure (N). Thus, the logarithm of N is the sum of the terms shown in Table III. This gave a multiple correlation coefficient of 0.96167. Table IV shows the correlation of the regression output to the input values of Table II.

TABLE IV
REGRESSION EQUATION CORRELATION

OBSERVED	PREDICTED						
	R=-0.60	R=0.02	R=0.10	R=0.25	R=0.40	R=0.50	R=0.60
4.0000	3.9473	3.9532	-	-	-	-	-
4.3010	4.4561	4.2822	4.3987	4.3372	-	-	-
4.4771	4.5001	4.4084	4.5079	4.5122	4.3652	4.5818	-
4.6021	4.5594	4.5682	4.5818	4.6042	4.3989	4.5777	4.4482
4.7782	4.6915	4.8329	4.7535	4.8307	4.6342	4.8648	4.8706
5.0000	4.9057	5.1857	4.9766	5.1665	5.0204	5.2530	5.2119
5.3010	5.3123	5.5398	5.3346	5.5763	5.5343	5.5250	5.5317
5.4771	5.5166	5.6817	5.4359	5.6798	5.6437	5.5505	5.5831
5.7782	5.8565	5.7428	5.5630	5.7331	5.7438	5.5892	5.6179
6.0000	5.9709	5.7925	5.6140	5.7547	5.7565	5.6022	5.6530

Although the regression predicted output does not look like a close correlation to the observed data, the error of the regression equation falls within the scatter band for the original data [Ref. 2].

III. DESCRIPTION OF ACQUISITION SYSTEM

The data acquisition system consists of an HP-9835 Desktop Computer (Controller), an HP-2240A Measurement and Control Processor (Processor), and a Materials Testing Machine (MTS). The Controller (Fig. 3) is used to generate the random loads, send the loads to the MTS through the Processor and manipulate the strain data that it receives back through the Processor. The Processor (Fig. 4) receives digital commands from the Controller to output specified analog values or to read analog values and send them in digital form to the Controller. The MTS (Fig. 5) is a hydraulic testing machine that applies loads specified by voltage signals to a test specimen.

The resident language in the Controller is BASIC in which all of the programs are written. Programs and data are stored on a built-in magnetic tape mass storage device. The Controller is linked to the Processor (or any other peripherals) through the HP-IB Interface Bus. This Bus has its own Read Only Memory (ROM) and address associated with the ROM. Each peripheral on the Bus also has its own HP-IB address. The Processor is addressed by the Controller through the HP-IB by use of the ENTER and OUTPUT commands, which include the device address and the data to be sent or requested.

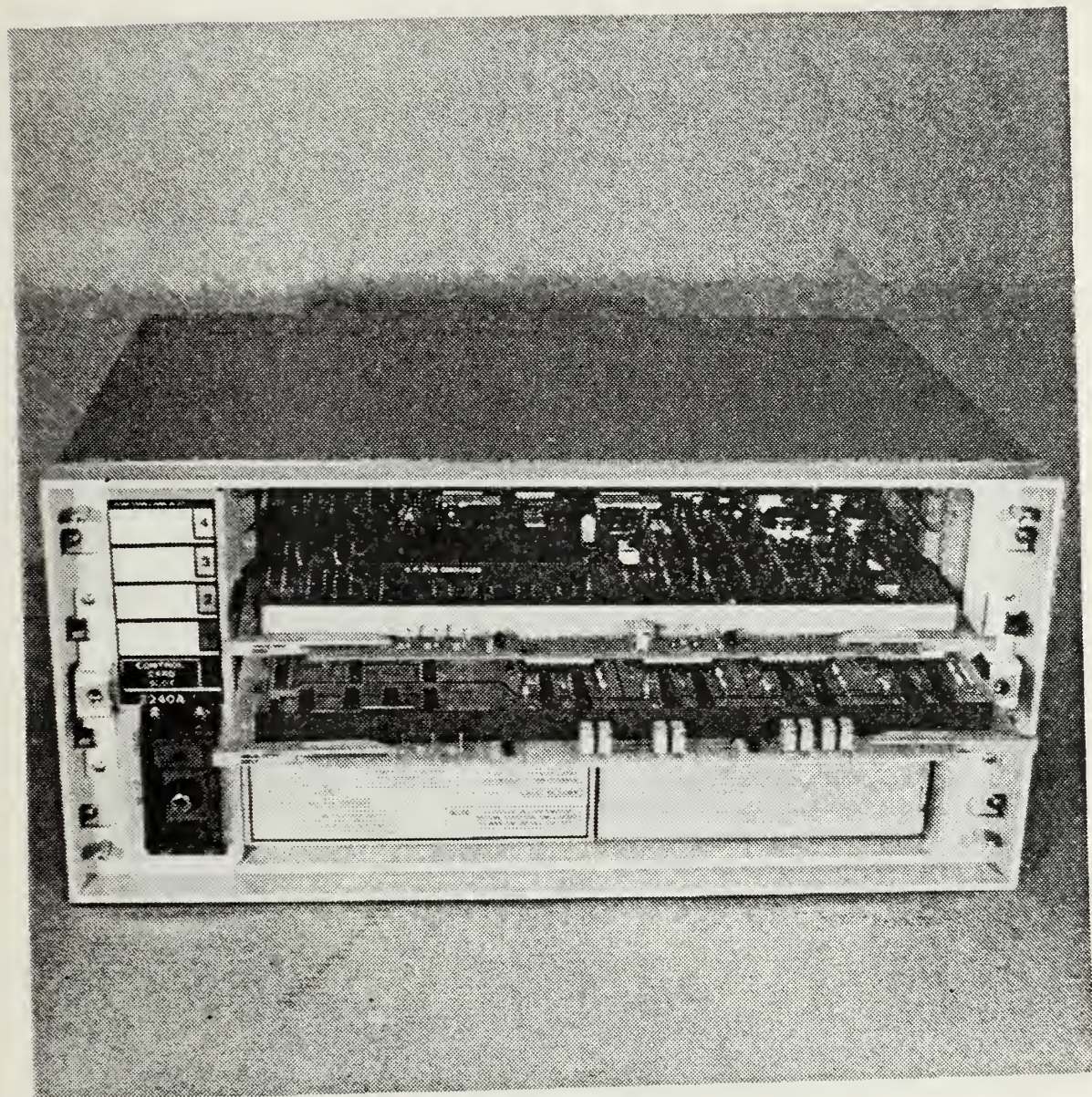


Figure 4. HP-2240A Measurement and Control Processor

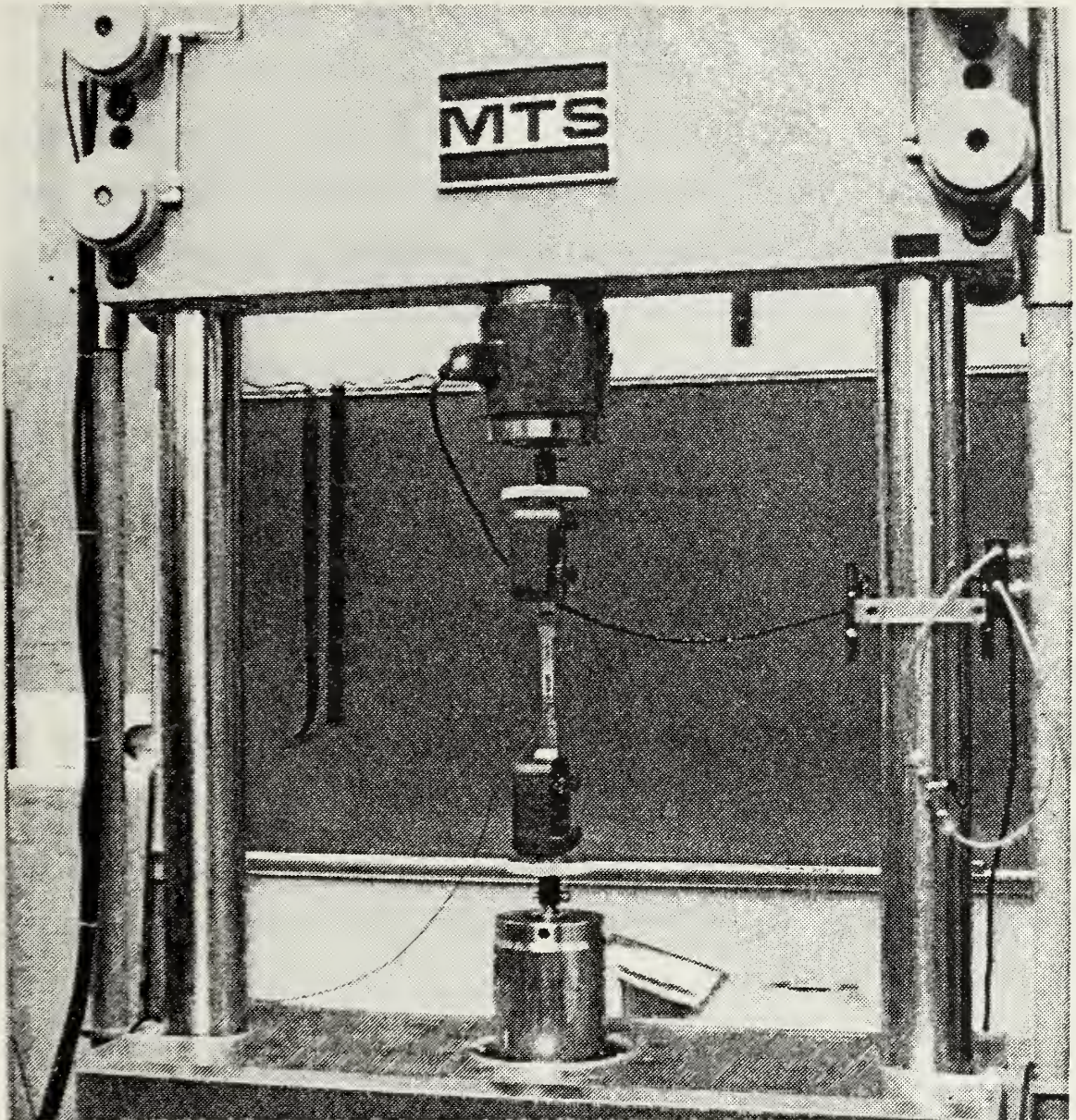


Figure 5. Materials Testing System (MTS)

The Processor has four function card slots. For this data acquisition system one D/A card and one A/D card were all that were necessary. The D/A card can handle up to four output channels, one is used to drive the MTS and another is used to drive a relay, which operates an automatic camera shutter. The A/D card can handle up to sixteen bi-polar channels. In this instance eight were used by the acquisition program for reading strain gages, and/or load cells. Commands are sent to the Processor in standard ASCII format, and an error code is sent back to the Controller.

The MTS is a 100,000 lb., closed loop, feedback controlled Materials Test System with a hydraulic actuator. The MTS can be used in either load, strain or displacement control modes. It can be used by itself with its own controller or its own function generator. In this case the output from the D/A card was input to the MTS in a load control mode. The signal from the Processor was output to the hydraulic system and the MTS checks itself with a load cell signal until the load is matched.

IV. DESCRIPTION OF PROGRAMS

There are three major programs written for the controller (in BASIC) for material properties and fatigue testing. The first is entitled AXIAL and is used to record data from a strain gaged specimen in an axial tension test to determine the Modulus of Elasticity, Poisson's Ratio and the Ramberg-Osgood coefficients for the plastic region. FLTTST, the second program, generates random ordered loads and outputs these loads through the PROCESSOR to the MTS System, which applies the loads to the specimen. The loads and the strains generated by this program are stored on tape for use later in data reduction. The last program, DAMAGE, takes the data generated by FLTTST and calculates the fatigue damage of the specimen.

A. PROGRAM AXIAL

AXIAL does not control the MTS System and so can be used with any system possessing voltage outputs for load and strain to record data. AXIAL records data while the testing machine performs an axial tension pull on a test specimen. The program is set up to read the load and both the longitudinal and transverse strains at equal intervals of time while the testing machine is used in a constant strain rate mode. The program can also be run using only the longitudinal strain gage in which case Poisson's ratio is not computed.

The loads are converted to stresses so that the program can work directly with the stress-strain relationships. After all the data has been taken, the program asks the user to specify the load at which the proportional limit seems to have been reached. This cutoff is entered so that a good linear fit can be made to find the Modulus of Elasticity (E). After the linear fit to obtain E, the value is output along with the slope intercept B and the correlation factor. The program then asks the user if a different fit is to be tried using a new proportional limit. If not, the program continues by computing Poisson's ratio and finds the Ramberg-Osgood coefficients using the Modulus of Elasticity previously found.

The Modulus of Elasticity is the most critical property found in AXIAL not only for its own value in calculating stresses and strains but also because the Ramberg-Osgood coefficients are based on E. For this reason a good linear fit is obtained by a routine that evaluates the perpendicular distances of the data points from the estimated fit. The E that has been calculated is output to the user along with the correlation factor so that a judgment can be made as to whether the estimated proportional limit should be changed in order to try for a better fit.

The equations governing the linear elastic portion of the stress-strain curve are:

$$\sigma_1 = A\varepsilon_1 + B \quad (6)$$

$$\sigma_1 = C\varepsilon_2 + D \quad (7)$$

where A is the modulus of elasticity (E). B and D are normally neglectibly small. Poisson's ratio is given by

$$\nu = - \frac{A}{C} \quad (8)$$

The plastic portion of the stress-strain curve can be approximated by the following equation:

$$\epsilon = \frac{\sigma}{E} + \beta \left(\frac{\sigma}{E} \right)^n \quad (1)$$

Beta and n can be found by performing a logarithmic curve fit of the data above the proportional limit, but the Ramberg-Osgood method gives as good a fit with fewer calculations. The Ramberg-Osgood relations are:

$$n = 1 + \frac{\log (17/7)}{\log (\sigma_{.7}/\sigma_{.85})} \quad (9)$$

$$\beta = \frac{3}{7} \left(\frac{E}{\sigma_{.7}} \right)^{n-1} \quad (10)$$

where,

$\sigma_{.7}$ = stress at the intersection of a line of slope .7E
and the stress-strain curve

$\sigma_{.85}$ = similarly computed with a slope of .85E.

Inputs for AXIAL are:

Maximum Strain for the test

Strain Rate to be used

Number of Data Points desired (1000 max)

Number of Strains to be recorded (1/2)

Cross Sectional Area of specimen

Load Scale Factor (pounds/millivolt)

Strain Scale Factor (microstrain/millivolt)

After the data run:

Maximum Load of Elastic Range (Proportional Limit)

B. PROGRAM FLTTST

The most critical program is FLTTST since it both controls the MTS and takes data. The key to FLTTST is the random selection of the load to be applied to the specimen. Using the Mil Spec 8866 Flight Loading Spectrum A for fatigue, percentages were calculated for the number of times each load is to be applied (Table V). These percentages were then totaled and left in decimal form as numbers between 0 and 1. Then, using the Controller's random number generator, the load to be applied is selected through a series of IF statements. For example, to select a load of 95% of limit load, a random number above 0.98462125 and below 0.99509594 has to be selected. If after going down through all of the IF statements a load is not selected, it would mean that the random number must be above 0.99961910, then 125 limit load has been selected, the MTS load is incremented in finite load steps that are user selected. When the desired load is reached, the Controller then requests that the Processor read the data channels. FLTTST then stores these data points on tape for future reduction. As each load to be output is selected, a count is kept of

that load so that the user can have an immediate output of the load distribution at the end of the run.

TABLE V
RANDOM NUMBER FOR SELECTING MANEUVER LOAD

<u>% Limit Load</u>	<u># Cycles</u>	<u>Random Number</u>
35	17,000	0.40470409
45	9,500	0.63086226
55	6,500	0.78560206
65	4,500	0.89272961
75	2,500	0.95224492
85	1,360	0.98462125
95	440	0.99509594
105	150	0.99866686
115	40	0.99961910

Inputs for FLTTST are:

Number of Hours to be simulated

Number of Data Readings (maximum of 8)

Load at One G (lbs)

Limit Load (lbs)

Load Scale of MTS (10,000;20,000;50,000;100,000)

Load Rate (lbs/sec), and

Data Reading Scale Factor (microstrain or pounds/
millivolt)

There is another program named RDDATA that may sometimes be needed after running FLTTST. If data from more than one strain gage or load cell were recorded on the data file from FLTTST, it is necessary to first run RDDATA to separate each data file under its own heading before proceeding with program DAMAGE. This was done to conserve time between data points taken and to extend the life of data tapes. It also conforms with program DAMAGE since it can only compute damage on one set of data at a time.

C. PROGRAM DAMAGE

The purpose of this program is to take the loading that was saved on tape with the FLTTST program and calculate the fatigue damage accumulated at the stress concentration site during the flight hours simulated. The program reads the recorded far-field loads in the order that they were applied to the specimen, calculates local stresses at the stress riser and then uses Miner's Law for calculating the cumulative damage. Once the load creates a stress in the critical area greater than the proportional limit, local stresses are calculated using a nonlinear stress-strain law and calculations for residual stresses and strains are made.

The maneuver load and the one G load stored immediately after it are read in together. The maneuver load is then converted to nominal or far-field stresses and local stresses using the following relations:

$$S = \frac{L}{A} \quad (11)$$

$$\sigma = K_t S \quad (12)$$

where,

S = nominal stress

L = applied load

A = minimum cross sectional area of specimen

σ = local stress

K_t = stress concentration factor

The local maneuver stress is checked against the proportional limit or the last largest plastic stress to see if it would cause plastic deformation. If plastic deformation is produced, then an iteration process must be performed to find the local stress, using the relation

$$K_t S = \sigma [1 + \beta (\frac{\sigma}{E})^{n-1}] \quad (2)$$

The routine to do this uses a modified false position method [Ref. 4]. With the local stress determined, residual stresses and strains are then calculated, using

$$\sigma_R = \sigma - [\sigma^2 + \frac{2n\beta E^2}{n+1} (\frac{\sigma}{E})^{n+1}]^{\frac{1}{2}} \quad (3)$$

$$\epsilon_R = \frac{\sigma_R}{E} + \beta (\frac{\sigma}{E})^n \quad (4)$$

If no new plastic deformations are caused but the plastic region has been entered before, then local stresses are calculated using

$$\sigma = \sigma_R + K_t S - E \epsilon_R [1 + \frac{S}{S_{Last\ Yield}}] \quad (5)$$

where $S_{\text{Last Yield}}$ is the largest nominal stress that has occurred

which produced local stresses into the plastic region.

Damage is then calculated using the current local stress and the ratio of the current stress to the stress at one G loading (R value).

Using Miner's Law:

$$D = \frac{1}{N} \quad (13)$$

where, N = number of cycles to failure and can be found using regression formulas that fit stress-fatigue data for 7075-T6 aluminum. The damage caused by this cycle is then added to the damage caused by the other cycles computed one load at a time until all the data has been read.

Inputs to DAMAGE are:

Minimum Cross Sectional Area (sq. in.)

Modulus of Elasticity (psi)

Ramberg-Osgood Coefficients, and

Proportional Limit (psi)

V. SAMPLE TEST

Several tests have been developed to evaluate both the programs and the program-acquisition system combined. AXIAL was checked by inputting stress and strain pairs taken from an existing Ramberg-Osgood representation of 7075-T6, and the results of the two were compared. FLTTST was checked by taking the output from the Processor (normally used to drive the MTS), routing the output from the output port to the input port and reading the output value on the data input port. Thus, the input port was getting input just as it normally would from a load cell. By doing this the actual voltages could be read directly from the output port with a voltage meter, and the input results could be treated as actual loads to check Program DAMAGE. This was checked by hand for both load spectrum and load accuracy. DAMAGE was checked by hand with sample runs through FLTTST as described above. Two full system tests were then run with the MTS, including photo-elastic pictures of the stress concentration area and strip chart recordings of the input and output loads.

A. PROGRAM AXIAL

The first test of AXIAL was performed by using the Ramberg-Osgood coefficients calculated by Kaiser [Ref. 5] to generate stress-strain pairs for manual input into the

program. The result should have been the same value for the modulus of elasticity and the Ramberg-Osgood coefficients as previously computed. Since a relatively small number of points were entered by hand (53) as compared to the number of points that will be taken by the program (1000), larger errors were expected on this test than will be expected on an actual data run. The results of the test are shown below.

<u>Kaiser</u>	<u>AXIAL</u>
E = 10.117E6	E = 10.113E6
n = 21.58	n = 23.475
β = 1.479343	β = 1.5177E47

This large difference (especially in β) was due to the stress-strain pairs being calculated in stress steps of 500 psi. The program, using 1000 points, will have a difference of approximately 16 psi between points. This will make the accuracy of the program better than the capability of the system to read loads and strains accurately.

The second test of AXIAL was an actual specimen tension test. A specimen of 7075-T6 Aluminum was fabricated from the same sheet stock as the notched panel specimens. This was inserted into the MTS machine which was operated in a constant strain rate mode. The specimen was loaded to produce a strain of 14,000 microinches/inch, at a strain rate of 1000 microinches/inch/minute. One thousand data points were taken at constant intervals of strain during the test. The program then computed the modulus of elasticity

and the Ramberg-Osgood coefficients. These were compared to hand calculations made from the Load vs. Strain plot made by the MTS. The results of both are listed below.

<u>AXIAL</u>	<u>Hand Calculation</u>
E = 9.5042E6	E = 9.5000E6
n = 31.2154	n = 33.0383
β = 3.1168E63	β = 9.7360E66

A plot of the actual data and the points computed using the calculated material properties are shown in Figure 6.

B. PROGRAM FLTTST

The first test performed with FLTTST was one to see if the random load spectrum followed and Mil Spec load spectrum. This was done by making several runs of 100 hour simulations and comparing the spectra (Table VI). As would be expected, the spectra did not match exactly due to the random way in which loads were chosen. The largest differences were in the area of the fewest loads, as also would be expected. A sample from a strip chart of the Processor output and the output from a load cell while the MTS is being driven by FLTTST is shown in Figure 7.

Several sample tests were run to check the accuracy of FLTTST and DAMAGE. Knowing that a full system test was going to be run, the sample tests were run using the material properties of the specimen (Fig. 1) to be used in the full scale tests. These material parameters and properties are:

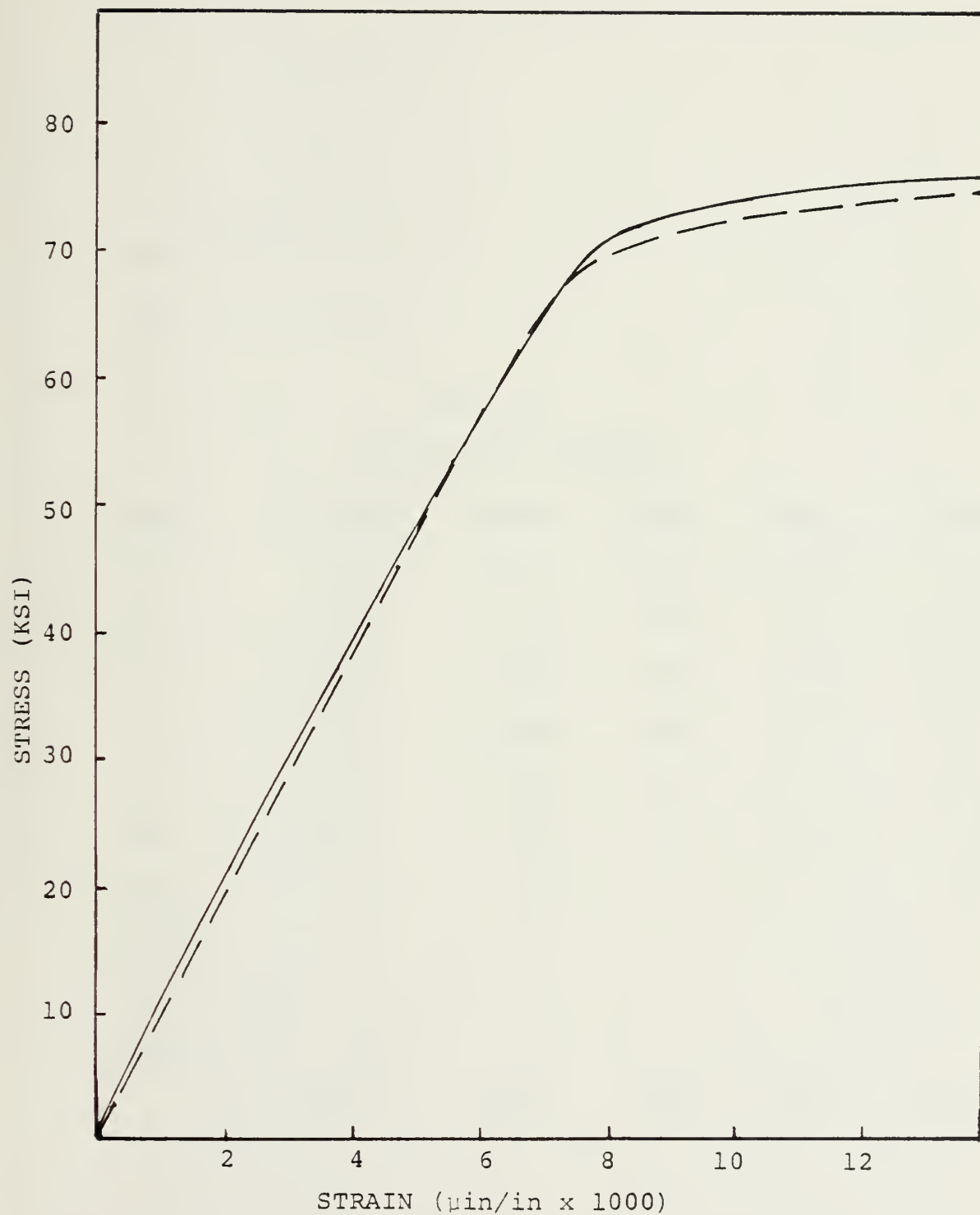


Figure 6. Axial Tension Test

$$A = .7136 \text{ sq. in.}$$

$$E = 10.12 \text{ E } 6 \text{ psi}$$

$$K = 2.73$$

$$\beta = 1.479 \text{ E } 43$$

$$n = 21.58$$

$$\sigma_Y = 72,000 \text{ psi}$$

$$\sigma_{ULT} = 82,000 \text{ psi}$$

$$\sigma_{PL} = 60,000 \text{ psi}$$

TABLE VI

SAMPLE LOAD SPECTRA

<u>% Load</u>	<u>MIL SPEC</u>	<u>100HR</u>	<u>100HR</u>	<u>100HR</u>	<u>100HR</u>
35	17000	1698	1726	1662	1721
45	9500	977	998	948	937
55	6500	658	637	690	646
65	4500	451	434	442	450
75	2500	228	234	246	250
85	1360	133	139	146	131
95	440	49	21	43	53
105	150	13	8	15	8
115	40	5	1	6	3
125	16	0	2	2	1
	<u>42006</u>	<u>4200</u>	<u>4200</u>	<u>4200</u>	<u>4200</u>

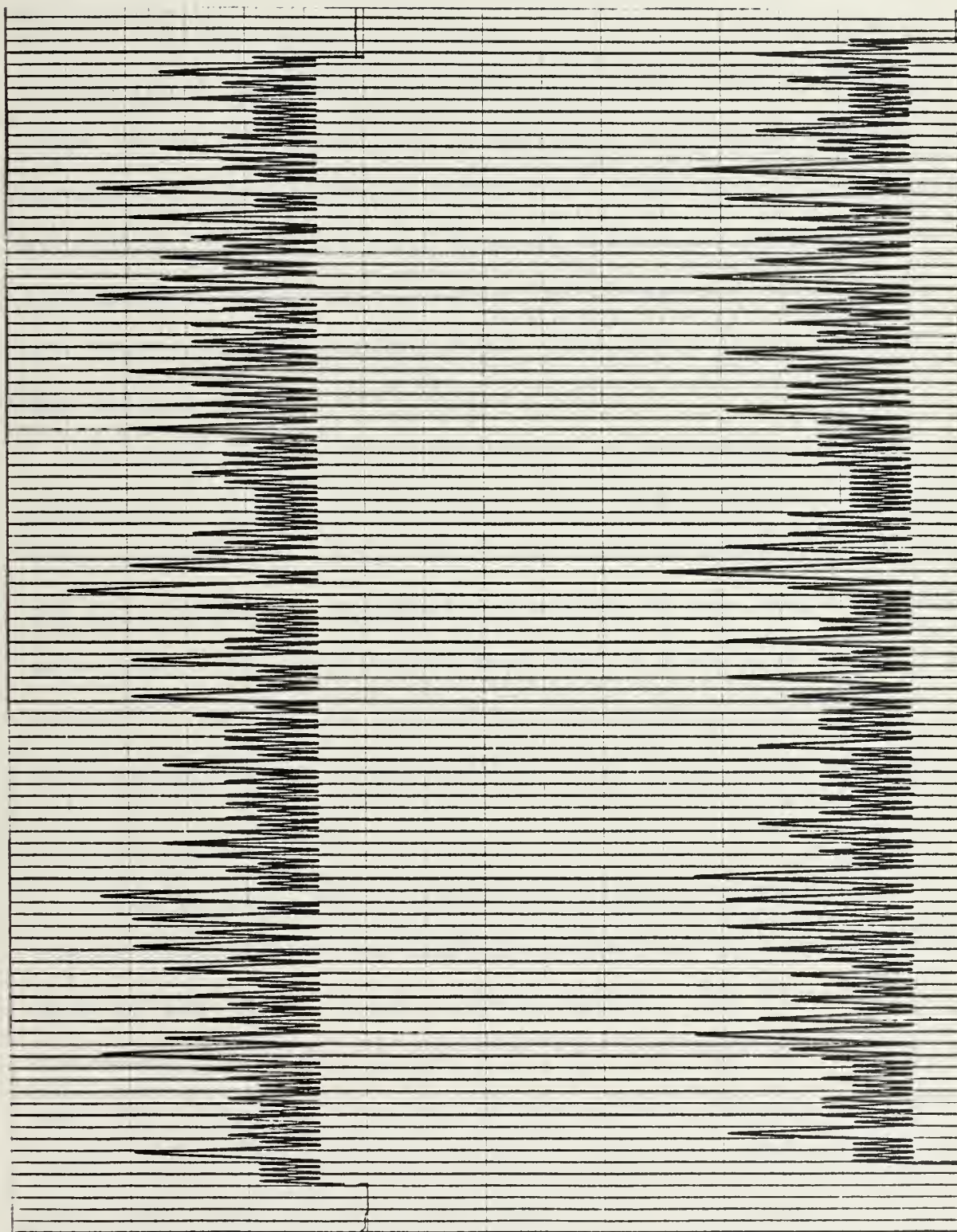


Figure 7. Sample Random Loading

For these uses the limit load was set at the load that would cause local yield stress or at two-thirds of the ultimate stress, whichever was the lower. In this case two-thirds the ultimate stress was the limiting factor which gave a limit stress of 54,667 psi, produced by a load of 14,289 lbs. Assuming a 6.5-g aircraft limit load, this gave a 1-g stress of 8409 psi, produced by a load of 2198 lbs. These are the limits asked for by the program FLTTST and all other loads are fractions of the limit load. The 1-g load is used as the minimum load in the fatigue cycle.

To check the accuracy and speed of different loading step sizes, sample calculations were performed and compared with the computed actual load that should be applied (Table VII). For this check the material properties of the sample specimen were used. The conclusions were that a step size of 25 should be used since this gives good accuracy and takes approximately four minutes per hour of flight time simulated.

C. PROGRAM DAMAGE

Further tests were performed primarily to check the DAMAGE program, but the FLTTST program was used to generate some of the loads to run through DAMAGE. The first was a handmade test of ten cycles that had one load that would send the specimen into the plastic region locally and other loads that would produce recordable damage. The purpose of this check was to check the program's calculation of the

STEP SIZE COMPARISONS

%LOAD	CALCULATED				STEP = 25				STEP = 100			
	<u>LOAD</u>	<u>S</u>	<u>Kt*S</u>	<u>LOAD</u>	<u>S</u>	<u>Kt*S</u>	<u>LOAD</u>	<u>S</u>	<u>LOAD</u>	<u>S</u>	<u>Kt*S</u>	
100	14289	20024	54665	14289	Not Computed	Not Computed	14289	Not Computed	14289	Not Computed	Not Computed	
1-9	2198	3080	8409	2150	3013	8225	2000	2803	2000	2803	7651	
35	5001	7008	19132	5050	7077	19320	5200	7287	5200	7287	19893	
45	6430	9011	24599	6450	9039	24676	6600	9249	6600	9249	25249	
55	7859	11013	30066	7900	11071	30223	8000	11211	8000	11211	30605	
65	9288	13016	35533	9300	13033	35579	9400	13173	9400	13173	35691	
75	10717	15018	41000	10750	15064	41126	10800	15135	10800	15135	41317	
85	12146	17021	46467	12150	17026	46482	12200	17096	12200	17096	46673	
95	13575	19023	51934	31600	19058	52029	13600	19058	13600	19058	52029	
105	15003	21024	57397	15050	21090	57576	15200	21300	15200	21300	58150	
115	16432	23027	62863	16450	23052	62932	16600	23262	16600	23262	63506	
125	17861	25029	68330	17900	25084	68480	18000	25224	18000	25224	68862	

PLASTIC STRESS COMPUTATIONS

%LOAD	PLASTIC STRESS COMPUTATIONS				PLASTIC STRESS COMPUTATIONS			
	<u>LOAD</u>	<u>S</u>	<u>STRESS</u>	<u>LOAD</u>	<u>S</u>	<u>STRESS</u>	<u>LOAD</u>	<u>STRESS</u>
115	16432	23027	62544	16544	23052	62605	16600	63116
125	17861	25029	66942	17900	25084	67046	18000	67306

residual stresses and strains and the difference in damage due to those residual stresses and strains. There were three loads that caused damage (85%, 95% and 125% limit load) and one load that caused local stresses above the proportional limit (125% limit load). Residual stresses and strains were calculated along with the total damage and compared with the program's results (Table VIII). Differences in calculations were within roundoff error.

TABLE VIII
TEN CYCLE LOAD SPECTRUM

<u>% LIMIT LOAD</u>	<u>LOAD (lbs)</u>	<u>STRESS</u>	<u>R</u>	<u>D</u>
35	5001.15	19133	0.4395	0
65	9387.85	35532	0.2367	0
45	6430.05	24599	0.3418	0
85	12145.70	46465	0.1810	1.0324E-6
125	17861.30	66944	0.1048	3.0193E-5
35	5001.15	17725	0.3957	0
95	13574.60	50488	0.1389	3.8419E-6
45	6430.05	23185	0.3025	0
75	10716.80	39567	0.1772	0
55	7858.95	28646	0.2448	0

HAND CALCULATION

$$\sigma_R = 1313 \text{ psi} \quad \epsilon_R = 7.3442\text{E-}6 \text{ in/in}$$

$$D = 3.5067\text{E-}5$$

PROGRAM CALCULATION

$$\sigma_R = -1313 \text{ psi} \quad \epsilon_R = 7.3443\text{E-}6 \text{ in/in}$$

$$D = 3.5077\text{E-}5 \quad \sigma = 66,944 \text{ psi}$$

The last set of tests ran the entire system. Program FLTTST was used to drive the MTS, and output from the MTS load cell was read by the program and stored on tape. Photoelastic pictures were taken of the specimen before the test and during the test at every load above 75% of the limit load. A strip chart reading of the program output and the load cell output (Fig. 7) were read out simultaneously to enable immediate analysis of the program load and MTS load correlation.

TABLE IX
THREE HOUR FLIGHT SIMULATION TEST

<u>#LOADS</u>	<u>%LOADS</u>	<u>STRESS</u>	<u>R</u>	<u>D</u>
2	85	46482	0.1770	1.0726E-6
3	95	52029	0.1581	4.4607E-6
2	105	57576	0.1429	1.2222E-5

HAND CALCULATION RESULTS

$$D = 3.9972E-5$$

PROGRAM RESULTS

$$D = 3.9902E-5$$

The first test was a three flight hour simulation and the second was a two-hour simulation. During both tests the highest load applied to the specimen was 105% of the limit load. By reference to Table VII, 105% of the limit

load does not cause local stresses above the proportional limit; therefore, no residual stresses need to be calculated and all the 1-g stresses will be the same. The results of the tests (Tables IX and X) show that the program and hand calculations agree within round-off error.

TABLE X
TWO HOUR FLIGHT SIMULATION TEST

<u>#LOAD</u>	<u>%LOAD</u>	<u>STRESS</u>	<u>R</u>	<u>D</u> <u>D</u>
3	85	46482	0.1770	1.0726E-6
1	105	57576	0.1429	1.2222E-5

HAND CALCULATION RESULTS

$$D = 1.5440E-5$$

PROGRAM RESULTS

$$D = 1.5534E-5$$

VI. CONCLUSIONS

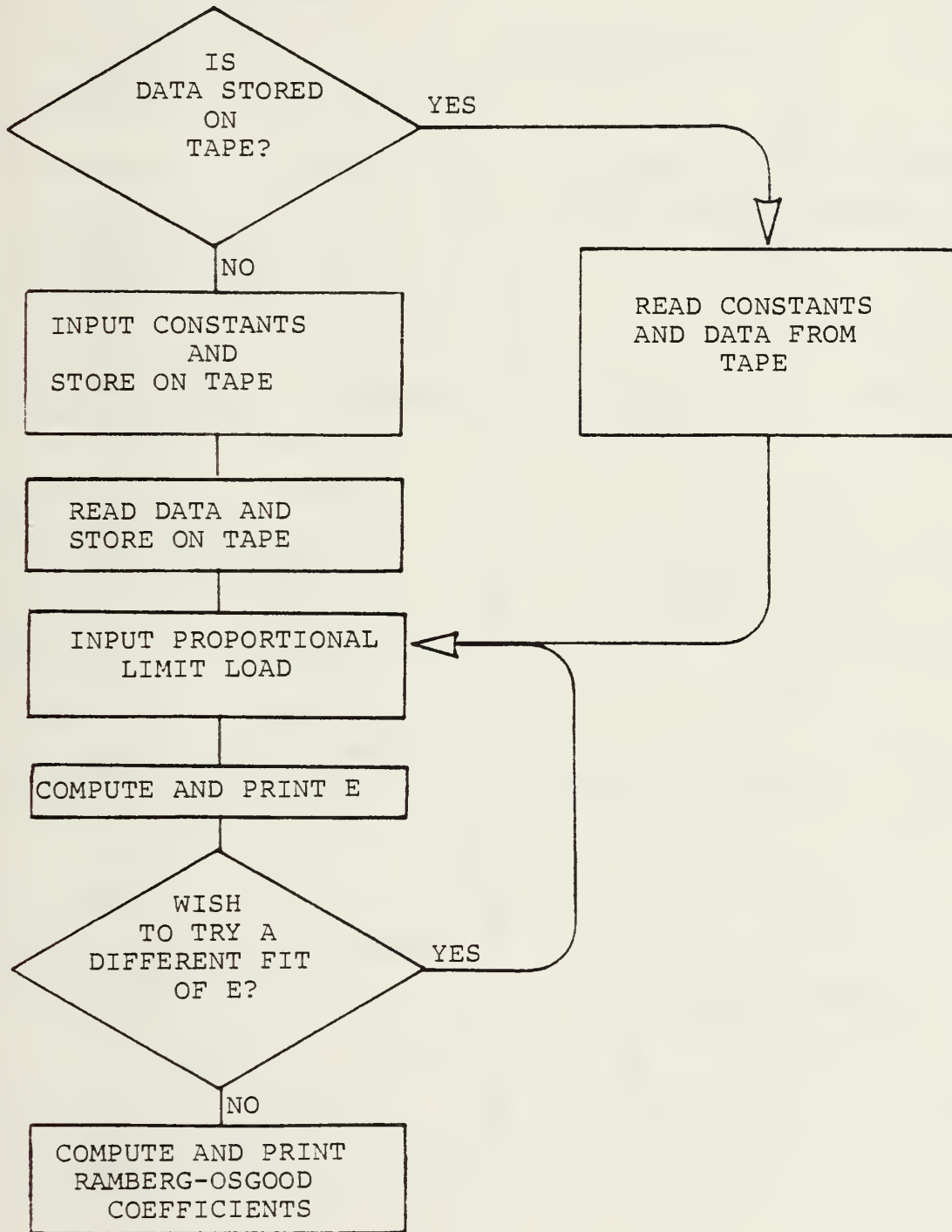
It is believed that this system will greatly simplify and increase the accuracy of predicting fatigue damage. Almost all of the calculations that would normally have to be done by hand, one step at a time, are now performed by the programs. A few of the input values were left as hand calculations as a safety feature, so that the user would be aware of the magnitude of the loads at which the MTS would be operating.

Although several tests and examples of program verification were included in this thesis, many more checks were performed to insure that the system was operating correctly. The only area in which problems occurred was with the Program AXIAL. If enough data points are not taken, E will still be evaluated correctly but the Ramberg-Osgood coefficients will suffer greatly in accuracy.

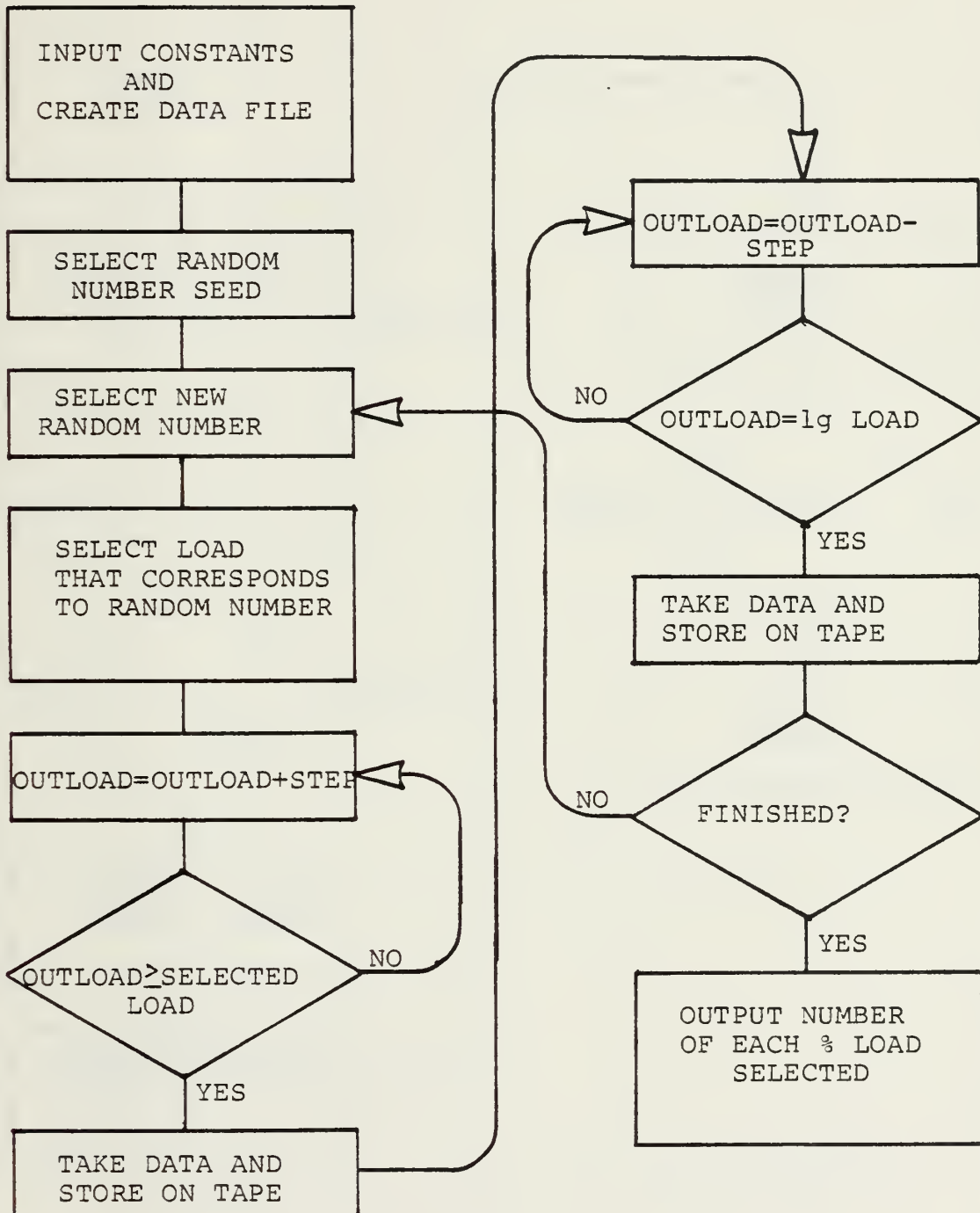
Even though these programs will greatly enhance analysis in the fatigue testing area, the potential of the data acquisition system has barely been tapped. The system as it now stands could handle over twice as much data input and output. With added control cards, the system could be expanded at least tenfold.

APPENDIX A
PROGRAM FLOW CHARTS

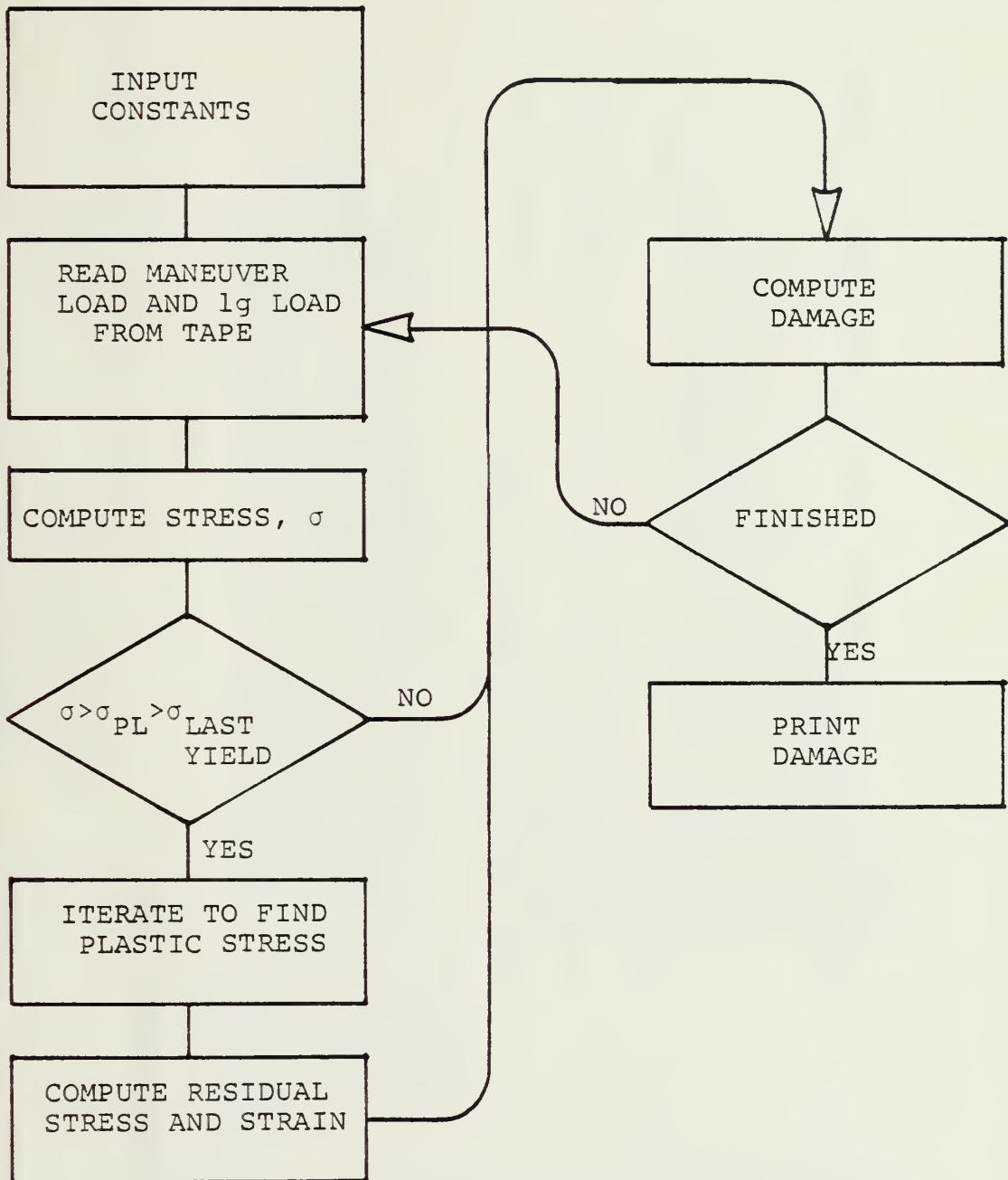
PROGRAM AXIAL



PROGRAM FLTTST



PROGRAM DAMAGE



APPENDIX B

PROGRAM LISTINGS

```

10 REM PROGRAM AUTO START
20 REM
30 LOAD KEY "KEYDAT"
40 PRINT "THE SYSTEM IS NOW SET TO USE FOR DATA ACQUISITION"
50 PRINT "FOR EITHER AN AXIAL MATERIALS TEST OF FATIGUE TESTING."
60 PRINT "TURN ON THE HP-2240A PROCESSOR AND ALLOW TO WARM UP FOR"
70 PRINT "AT LEAST FIVE (5) MINUTES. THE FOLLOWING IS A LIST OF"
80 PRINT "PROGRAMS AVAILABLE AND THEIR GENERAL PURPOSE. BY EXECUTING"
90 PRINT "THE SPECIAL KEY THE PROGRAM SELECTED WILL BE LOADED."
100 PRINT "PRESS RUN FOR EXECUTION. EACH PROGRAM HAS A DETAILED"
110 PRINT "DESCRIPTION OF ITS USE AT THE START."
120 PRINT " "
130 PRINT "KO AXIAL MATERIAL PROPERTIES TEST."
140 PRINT " COMPUTES MODULUS OF ELASTICITY AND POISSON'S RATIO."
150 PRINT "K1 FLIGHT LOADING TEST."
160 PRINT " APPLIES RANDOM LOADS AND TAKES UP TO EIGHT STRAIN"
170 PRINT " READINGS AND STORES ON TAPE FILE."
180 PRINT "K2 READ DATA."
190 PRINT " SEPARATES STRAINS ON TAPE GENERATED BY FLIGHT"
200 PRINT " TEST ONTO A SEPARATE TAPE FOR EACH STRAIN"
210 PRINT " AND LISTS A PRINTOUT OF THAT DATA SET."
220 PRINT " MUST BE RUN BEFORE 'DAMAGE' IF MORE THAN ONE"
230 PRINT " DATA SET WAS TAKEN."
240 PRINT "K3 DAMAGE CALCULATION."
250 PRINT " CALCULATES THE FATIGUE DAMAGE DONE DURING FLIGHT"
260 PRINT " TEST"
270 END

```


KEY 0
-KEY 7
"AXIAL"
-EXECUTE

KEY 1
-KEY 7
"FLTTST"
-EXECUTE

KEY 2
-KEY 7
"RDDATA"
-EXECUTE

KEY 3
-KEY 7
"DAMAGE"
-EXECUTE


```

10 PRINT "THIS PROGRAM IS FOR AXIALLY TESTING A MATERIAL SPECIMEN"
20 PRINT " TO FIND THE MODULUS OF ELASTICITY, POISSON'S RATIO AND"
30 PRINT "THE RAMSBURG-OSGOOD COEFFICIENTS FOR THE PLASTIC REGION."
40 PRINT "TWO STRAINS (LONGITUDINAL AND TRANSVERSE) HAVE TO BE INPUT"
50 PRINT "FOR POISSON'S RATIO TO BE COMPUTED. THE LOAD SHOULD"
51 PRINT "INPUT ON CHANNEL ONE (1). THE LONGITUDINAL"
60 PRINT "STRAIN SHOULD BE ON CHANNEL TWO (2). AFTER THE RUN HAS"
70 PRINT "BEEN MADE THE PROGRAM WILL ASK FOR THE MAXIMUM ELASTIC
80 PRINT "LOAD IN ORDER TO COMPUTE E. AFTER COMPUTING E IT WILL"
90 PRINT "PRINT IT ALONG WITH THE CORRELATION FACTOR AND ASK IF"
100 PRINT "YOU WISH TO TRY ANOTHER FIT. THEN THE RAMSBURG-OSGOOD"
110 PRINT "COEFFICIENTS WILL BE COMPUTED."
120 REM
130 REM MAIN PROGRAM FOR MATERIALS TESTING
140 REM
150 DIM LOAD (1000), E1(1000), E2(1000), SIGMA(1000)
160 INPUT "MAX STRAIN/DISPLACEMENT/LOAD? (IN/IN, IN/LBS)," EMX
170 INPUT "STRAIN/DISPLACEMENT/LOAD RATE? (IN, LBS/MIN)," RATE
180 INPUT "NUMBER OF DATA POINTS:," DPTS
190 INPUT "NUMBER OF STRAINS (1/2)," NSTRN
200 INPUT "CROSS-SECTION AREA:," AREA
201 INPUT "LOAD SCALE FACTOR:," LF
202 INPUT "STRAIN SCALE FACTOR:," SF
210 WAIT-TIME=EMX*60000/(RATE*DPTS)
220 DISP "WHEN READY TO START TAKING DATA HIT CONTINUE"
230 PAUSE
231 DISP "RUNNING"
240 FOR I=1 TO DPTS
250   OUTPUT 701; "A1, 2, 1, 3:"
260   ENTER 701;CODE, LOAD(I), E1(I), E2(I)
270   IF CODE()=0 THEN 250
271   WAIT WAIT-TIME
280 NEXT I
290 CALL DATA-CONV(LOAD(*), E1(*), E2(*), SIGMA(&), AREA, DPTS, LF, SF)
300 INPUT "INPUT MAX LOAD OF ELASTIC RANGE:," ELMAX
310 FOR N=1 TO DPTS
320   IF LOAD(N) > ELMAX THEN 340
330 NEXT N

```



```

330 NEXT N
340 NN=N-1
350 CALL LINFIT(EL(*), SIGMA(*), E, B, RCORR, NN)
360 PRINT "E="; E, "B="; B, "CORRELATION FACTOR="; RCORR
370 IF NSTRN=1 THEN 420
380 CALL LINFIT(E2(*), SIGMA(*), C, D, RCORR, NN)
390 PRINT "C="; C, "D="; D, "CORRELATION FACTOR="; RCORR
400 PRATIO=-E/C
410 PRINT "POISSON'S RATIO="; PRATIO
420 INPUT "WISH TO TRY ANOTHER FIT? (Y/N," ANS$
440 IF ANS$="Y" THEN 300
450 CALL RAMS-OSG(SIGMA(*), EL(*), E, BETA, NEX, DPTS)
460 PRINT "BETA="; BETA, "N="; NEX
470 STOP
480 END
490 SUB LINFIT (XOBS (*), YOBS (*), SloPE, B, RCORR, M)
500 SMXPSQ=SMYPSQ=SMXPYP=SUMX=SUMY=0
510 RECIPM=1/(1*M)
520 FOR I=1 TO M
530     SUMX=SUMX+XOBS(I)
540     SUMY=SUMY+YOBS(I)
550 NEXT I
560 XBAR=SUMX*RECIPM
570 YBAR=SUMY*RECIPM
580 REM NORMALIZE DATA POINTS, COMPUTE MEANS
590 XBARRC=1/XBAR
600 YBARRC=1/YBAR
610 FOR I=1 TO M
620     XPRIME=XBARRC*(XOBS(I)-XBAR)
630     YPRIME=YBARRC*(YOBS(I)-YBAR)
640     SMXPSQ=SMXPSQ+XPRIME*XPRIME
650     SMYPSQ=SMYPSQ+YPRIME*YPRIME
660     SMXPYP=SMXPYP+XPRIME*YPRIME
670 NEXT I
680 REM SOLVE FOR NORMALIZED SLOPE
690 DISC=SQR((SMYPSQ-SMXPSQ)^2+4*SMXPYP^2)
700 MPRIME=(SMYPSQ-SMXPSQ+DISC)/(2*SMXPYP)
710 REM COMPUTE SLOPE OF UNNORMALIZED BEST LINE
720 SLOPE=MPRIME*YBAR*XBARRC

```



```

740 B=YBAR-SLOPE*XBAR
750 REM COMPUTE REGRESSION POINTS FOR DEVIAT
760 SLREC�=-1/SLOPE
770 DETER=1/(SLOPE-SLREC�)
780 DEVIAT=0
790 FOR I=1 TO M
800 XREG=(YOBŠ(I)-SLREC�*XOBŠ(I)-B)*DETER
810 YREG=(SLOPE*YOBŠ(I)+XOBŠ(I)-SLREC�*B)*DETER
820 DELX=XREG-XOBŠ(I)
830 DELY=YREG-YOBŠ(I)
840 DEVIAT=DEVIAT+SQR(DELX2+DELY2)
850 SUMXR=SUMXR+(XOBŠ(I)-XBAR)2
860 SUMYR=SUMYR+(YOBŠ(I)-YBAR)2
870 NEXT I
880 RCORR=SLOPE*SQR(SUMXR/SUMYR)
890 SUBEND
900 SUB DATA-CONV(LOAD(*), E1(*), E2(*), SIGMA(*), AREA, DPTS, LF, SF)
910 FOR I=1 TO DPTS
920 SIGMA(I)=LOAD(I)*LF/AREA
930 E1(I)=E1(I)*1.0E-6*SF
940 E2(I)=E2(I)*1.0E-6*SF
950 NEXT I
960 SUBEND
970 SUB RAMS-OSG(SIGMA(*), E1(*), E, BETA, NEX, DPTS)
980 FOR I=1 TO DPTS
990 EP85=SIGMA(I)/(.85*E)
1000 M=I
1010 IF EP85(E1(I)) THEN 1030
1020 NEXT I
1030 FOR II=1 TO DPTS
1040 EP70=SIGMA(II)/(.7*E)
1050 N=II
1060 IF EP70(E1(II)) THEN 1080
1070 NEXT II
1080 IF ABS(E1(M)-EP85)(ABS(E1(M-1)-EP85)) THEN 1110

```



```

1090 SIG85=SIGMA(M-1)
1100 GO TO 1120
1110 SIG85=SIGMA(11)
1120 IF ABS(E1(N)-EP70) (ABS(E1(N-1)-EP70) THEN 1150
1130 SIG70=SIGMA(N-1)
1140 GO TO 1160
1150 SIG70=SIGMA(N)
1160 NEX=1+LOG(17/7)/LOG(SIG70/SIG85)
1170 BETA=3/7*(E/SIG70)↑(NEX-1)
1180 SUBEND

```



```

10 PRINT " THIS PROGRAM USES THE HP-2240A TO INTERFACE WITH THE"
20 PRINT "MTS SYSTEM TO OUTPUT LOAD AND TAKE DATA, TURN THE 2240A"
30 PRINT "ON AND ALLOW A FIVE MINUTE WARM-UP BEFORE USING."
40 PRINT " THE PROGRAM PRODUCES RANDOM LOADS TO MEET THE MIL SPECS"
50 PRINT "FOR FATIGUE PER 1000 FLIGHT HOURS. THE LOADS THAT MUST BE"
60 PRINT "ENTERED ARE THE CALCULATED 1 G AND LIMIT LOADS FOR THE SPEC-"
70 PRINT "IMEN BEING TESTED. THE MAXIMUM LOAD WILL BE 125% OF THE"
80 PRINT "LIMIT LOAD SO BE SURE THAT THE MTS IS SET ON THE PROPER SCALE."
90 PRINT "THE NUMBER OF FLIGHT HOURS THAT THE SPECIMEN IS TO BE TESTED"
100 PRINT "CAN BE SPECIFIED BY THE USER AND THE PROGRAM WILL USE PROBAB-"
110 PRINT "ILITY TO DETERMINE THE ACTUAL NUMBER OF LOADS. A PRINT-OUT"
120 PRINT "OF THE NUMBER OF LOADS IN EACH PERCENT OF LIMIT LOAD WILL"
130 PRINT "BE AT THE END OF THE PROGRAM."
140 PRINT " DATA TAKEN WILL BE STORED ON TAPE UNDER THE NAME SPECIFIED"
150 PRINT "BY THE USER, ALL DATA WILL BE STORED USING SHORT PRECISION"
160 PRINT "AND THE FIRST THREE ENTRIES WILL BE: NUMBER OF STRAINS,"
170 PRINT "NUMBER OF FLIGHT HOURS TESTED, AND NUMBER OF DATA POINTS."
180 PRINT "THE MAXIMUM NUMBER OF STRAINS IS EIGHT."
190 REM
200 REM
210 REM PARAMETER INPUT SECTION
220 REM
230 REM
240 OVERLAP
250 OPTION BASE 1
260 INTEGER NUMSTRAIN
270 SHORT ST(8)
280 SHORT NUMHRS, NUMPTS
290 INPUT "NAME OF DATA FILE?", A$
300 INPUT "NUMBER OF FLIGHT HOURS?", NUMHRS
310 INPUT "NUMBER OF DATA READINGS? (MAXIMUM 8)," NUMSTRAIN
320 NUMPTS=42006*NUMHRS/1000
330 NUMREC=(8*NUMSTRAIN*NUMPTS+12)/256+1
340 CREATE A$, NUMREC
350 ASSIGN #1 TO A$
360 BUFFER #1
370 PRINT #1; NUMSTRAIN, NUMHRS, NUMPTS
380 INPUT "ONE G LOAD? (LBS)," ONEGLOAD

```



```

390 INPUT "LIMIT LOAD? (LBS), " LIMLOAD
400 INPUT "MT'S SCALE? (10000, 20000, 50000, 100000,)," SCALE
410 ONEGLOAD=ONEGLOAD*10000/SCALE
420 LIMLOAD=LIMLOAD*10000/SCALE
430 INPUT "LOADING STEP SIZE? (25 TYP.)," STEP
440 INPUT "DATA READING SCALE FACTOR? (MICROSTRAIN/MILLIVOLT OR LBS/MILLIVOLT)
,STRAINSCALE
450 INPUT "PERCENT OF LIMIT LOAD ABOVE WHICH PHOTOS WILL BE TAKEN," PF
460 PHOTO-FLAT=PF/100
470 DISP "WHEN READY TO RUN HIT CONTINUE"
480 PAUSE
490 REM
500 REM
510 REM OUTPUT RANDOMIZED LOADS AND TAKE DATA
520 REM
530 REM
540 OUTPUT 701; "AO, 1, 2, 1, 0!"
550 OUTPUT 701; "AC, 2!"
560 DISP "RUNNING"
570 RANDOMIZE
580 PRINT "LOAD AT WHICH PHOTO WAS TAKEN (LBS)"
590 FOR J=1 TO NUMPT'S
600 SEED=RND
610 IF SEED(17000/42006 THEN 710
620 IF SEED(26500/42006 THEN 740
630 IF SEED(33000/42006 THEN 770
640 IF SEED(27500/42006 THEN 800
650 IF SEED(40000/42006 THEN 830
660 IF SEED(41360/42006 THEN 860
670 IF SEED(41800/42006 THEN 890
680 IF SEED(41950/42006 THEN 920
690 IF SEED(41990/42006 THEN 950
700 GOTO 980
710 XLOAD=.35*MLOAD
720 NUM35=NUM35+1
730 GOTO 1000
740 XLOAD=.45*LIMLOAD
750 NUM45=NUM45+1

```



```

11140 NEXT I
11150 OUTLOAD=OUTLOAD-STEP
11160 OUTPUT 701; "A0, 1, 1, 1,"OUTLOAD,"!"
11170 IF OUTLOAD)ONEGLOAD THEN 11150
11180 FOR I=1 TO NUMSTRAIN
11190 OUTPUT 701;"AI, 2,"I,"1:"
11200 ENTER 701;C,ST(I)
11210 IF C=1 THEN 11190
11220 ST(I)=ST(I)*STRAINSSCALE
11230 PRINT #1;ST(I)
11240 NEXT I
11250 NEXT J
11260 OUTPUT 701;"A0,1,1,1,0:"
11270 OUTPUT 701;"A0,1,2,1,10000:"
11280 WAIT 200
11290 OUTPUT 701;"a0,1,2,1,0:"
11300 PRINT "PERCENT LIMIT LOAD," "NUMBER OF LOADS"
11310 PRINT "35," NUM35
11320 PRINT "45," NUM45
11330 PRINT "55," NUM55
11340 PRINT "65," NUM65
11350 PRINT "75," NUM75
11360 PRINT "85," NUM85
11370 PRINT "95," NUM95
11380 PRINT "105," NUM105
11390 PRINT "115," NUM115
11400 PRINT "125," NUM125
11410 DISP "END"
11420 END

```



```

10 PRINT "THIS PROGRAM TAKES DATA THAT HAS BEEN STORED"
20 PRINT "WITH THE 'FLITST' PROGRAM AND SEPARATES THE"
30 PRINT "DIFFERENT STRAINS OR LOADS RECORDED AND STORES"
40 PRINT "EACH ON ITS OWN SEPARATE FILE. HOWEVER, IT ONLY"
50 PRINT "DOES THIS FOR ONE STRAIN AT A TIME. THE PROGRAM"
60 PRINT "WILL HAVE TO BE RE-ENTERED FOR EACH STRAIN THAT"
70 PRINT " IS TO BE SEPARATED. THE REQUIREMENTS FOR THIS"
80 PRINT "PROGRAM ARE THE NAMES OF THE ORIGINAL DATA FILE"
90 PRINT "AND THE NAME OF THE NEW FILE TO BE CREATED."
100 OPTION BASE 1
110 SHORT ST(8)
120 SHORT NUMHRS, NUMPTS
130 INTEGER NUMSTRAIN
140 SHORT STS
150 INPUT "NAME OF DATA FILE?", A$
160 ASSIGN #1 to A$
170 BUFFER #1
180 READ #1; NUMSTRAIN, NUMHRS, NUMPTS
190 PRINT "STRAINS," "FLIGHT HOURS," "DATA POINTS"
200 PRINT NUMSTRAIN, NUMHRS, NUMPTS
210 INPUT "STRAIN TO BE READ? (1-8)," STNUM
220 INPUT "NAME OF NEW FILE?", B$
230 NUMREC=(8*NUMPTS+3)/256+1
240 CREATE B$, NUMREC
250 ASSIGN #2 to B$
260 BUFFER #2
270 PRINT #2; NUMSTRAIN, NUMHRS, NUMPTS
280 FOR I=1 to NUMPTS*2
290 FOR J=1 to NUMSTRAIN
300 READ #1; ST(J)
310 NEXT J
320 STS=ST(STNUM)
330 PRINT #2; STS
340 NEXT I
350 READ #2, I
360 READ #2; NUMSTRAIN, NUMHRS, NUMPTS
370 PRINT "FLIGHT HOURS," "DATA POINTS"

```



```
380 PRINT NUMHRS, NUMPTS
390 PRINT "LOADED," "1 G"
400 FOR I=1 TO NUMPTS*2 STEP 2
410 READ #2; STSLOAD, STSIG
420 PRINT STSLOAD, STSIG
430 NEXT I
440 END
```



```

10 PRINT "THIS PROGRAM IS USED TO CALCULATE FATIGUE DAMAGE"
20 PRINT "FROM DATA OBTAINED BY USING THE FLIGHT TEST PROGRAM."
30 PRINT "THE FOLLOWING INPUTS ARE NEEDED FOR THE PROGRAM:"
40 PRINT "  AREA          CROSS SECTIONAL AREA OF SPECIMEN"
50 PRINT "  E            MODULUS OF ELASTICITY"
60 PRINT "  BETA, N        RAMSBURG-OSGOOD COEFFICIENTS"
70 PRINT "  KT            STRESS CONCENTRATION FACTOR"
80 PRINT "  LIMIT          PROPORTIONAL LIMIT"
90 PRINT "THE PROGRAM USES MINER'S METHOD TO CALCULATE THE DAMAGE."
100 PRINT "AFTER THE PROPORTIONAL LIMIT HAS BEEN PASSED THE RESIDUAL"
110 PRINT "STRESS AND STRAIN ARE CALCULATED AND ALL STRESSES ARE THEN"
120 PRINT "CALCULATED WITH CORRECTIONS FOR RESIDUAL STRESS AND STRAIN."
130 REM
140 REM
150 REM MAIN PROGRAM FOR DAMAGE CALCULATION
160 REM
170 REM
180 SHORT NUMHRS, NUMPTS, LOAD, ONEGLOAD, NUMST
190 COM E, BETA, CN, KT, SIGY, SL, SYMAX, D
191 D=0
200 INPUT "AREA?", AREA
210 INPUT "MODULUS OF ELASTICITY?", E
220 INPUT "RAMSBURG-OSGOOD COEFFICIENT, BETA?", BETA
230 INPUT "EXPONENT, N?", CN
240 INPUT "STRESS CONCENTRATION FACTOR, KT?", KT
250 INPUT "PROPORTIONAL LIMIT?", SIGY
260 INPUT "NAME OF DATA FILE?", A$
270 ASSIGN #1 to A$
280 BUFFER #1
290 READ #1; NUMST, NUMHRS, NUMPTS
300 PRINT "FLIGHT HOURS = ", NUMHRS
310 PRINT "NUMBER OF DATA POINTS = ", NUMPTS
320 I=1
330 IF I)=NUMPTS THEN 600
340 READ #1; LOAD, ONEGLOAD
350 I=I+1
360 SL=LOAD/AREA
370 SIG=ONEGLOAD/AREA

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380 SIGL=SL*KT
390 SIGG=SIG*KT
400 IF SIGL)SIGY THEN 430
410 CALL DAMCALC(SIGL, SIGLG, D)
420 GOTO 330
430 CALL FINDSIG(SIGL)
440 PRINT "INTO PLASTIC RANGE, SIGMA=";SIGL
441 SIGMAX=SIGL
450 SYMAX=SL
460 SIGR=SIGL-SQR(SIGL↑2+2*CN*BETA*E↑2*(SIGL/E)↑(CN+1)/(CN+1))
470 EPR=SIGR/E+BETA*(SIGL/E)↑CN
480 SIGLG=SIGR+KT*SIG-E*EPR*(1+SIG/SYMAX)
481 PRINT " RESIDUAL STRESS=";SIGR
482 PRINT " RESIDUAL STRAIN=";EPR
483 PRINT " NEW I-G STRESS=";SIGLG
490 CALL DAMCALC(SIGL,SIGLG,D)
500 IF I)=NUMPTS THEN 600
510 READ #1; LOAD, ONEGLOAD
520 I=I+1
530 SL=LOAD/AREA
540 SIG=ONEGLOAD/AREA
560 SIGL=SIGR+KT*SL-E*EPR*(1+SL/SYMAX)
561 IF SIGL)SIGMHX THEN 430
570 SIGLG=SIGR+KT*SIG-E*EPR*(1+SIG/SYMAX)
580 CALL DAMCALC(SIGL, SIGLG,D)
590 GOTO 500
600 PRINT "FLIGHT HOURS," "DAMAGE"
610 PRINT NUMHRS, D
620 END
630 SUB FINDSIG(SIGL)
640 COM E, BETA, CN, KT, SIGY, SL, SYMAX
650 SIG1=SIGY*.7
660 SIG2=SL*KT
670 CN1=CN-1
680 F1=KT-(1+BETA*(SIG1/E)↑CN1)*SIG1/SL
690 F2=KT-(1+BETA*(SIG2/E)↑CN1)*SIG2/SL
700 X=(SIG1*F2-SIG2*F1)/(F2-F1)
710 FX=KT-(1+BETA*(X/E)↑CN1)*X/SL

```



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710 FX=KT-(1+BETA*(X/E)↑CN1)*X/SL
720 IF ABS(F1)).0000001 THEN 750
730 SIGL=SIG1
740 SUBEXIT
750 IF ABS(F2)).0000001 THEN 780
760 SIGL=SIG2
770 SUBEXIT
780 IF F1*F2)0 THEN 830
790 SIG2=X
800 F2=FX
810 F1-F1/2
820 GOTO 680
830 SIG1=X
840 F1=FX
850 F2=F2/2
860 GOTO 680
870 SUBEND
880 SUB DAMCALC(SIGL, SIG1G, D)
890 R=SIG1G/SIGL
900 S=SIGL/10000
910 N1-12.6452-1.92662*S+.00281098*S↑4-3.10691E-7*S↑8
920 N2=-12.8099*R 2+212.476+R↑6-86.765*R↑8+3.688*S*R
930 N3=-.11272*S↑3*R+.00104762*S↑5*R+3.39637E-6*S↑7*R↑3
940 N4=-.0350885*S↑3*R↑4-.0161827*S↑4*R↑6-34.4642*S*R↑9
951 NN=N1+N2+N3+N4
952 IF NN)6 THEN 990
960 N=10↑NN
980 D=D+1/N
990 SUBEND

```


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